Journal of Human Sport and Exercise
E-ISSN: 1988-5202
jhse@ua.es
Universidad de Alicante
España

BARBOSA, TIAGO M.; COSTA, MÁRIO J.; MARQUES, MÁRIO C.; SILVA, ANTÓNIO J.; MARINHO, DANIEL A.

A model for active drag force exogenous variables in young swimmers

Journal of Human Sport and Exercise, vol. 5, núm. 3, 2010, pp. 379-388
Universidad de Alicante
Alicante, España

Original Article

A model for active drag force exogenous variables in young swimmers

TIAGO M. BARBOSA[1,4] ✉, MÁRIO J. COSTA[1,4], MÁRIO C. MARQUES[2,4], ANTÓNIO J. SILVA[3,4], DANIEL A. MARINHO[2,4]

[1]*Polytechnic Institute of Bragança, Bragança, Portugal*

[2]*Department of Sports Sciences, University of Beira interior, Covilhã, Portugal*

[3]*Department of Sports Sciences, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal*

[4]*Research Centre in Sports, Health and Human Development, Vila Real, Portugal*

ABSTRACT

Barbosa TM, Costa MJ, Marques MC, Silva AJ, Marinho DA. A model for active drag force exogenous variables in young swimmers. *J. Hum. Sport Exerc.* Vol. 5, No. 3, pp. 379-388, 2010. The aim of the current study was to develop a structural equation modeling (i.e., path-flow analysis model) for active drag force based on anthropometric, hydrodynamic and biomechanical variables in young swimmers. The theoretical model was developed according to main review papers about these determinants. Sixteen male swimmers (12.50±0.51 years-old; Tanner stages' 1-2) were evaluated. It was assessed: (i) anthropometrical variables such as body mass, height, frontal surface area; (ii) hydrodynamic variables including drag coefficient and active drag with the velocity perturbation method; (iii) the biomechanical variables stroke length, stroke frequency and swimming velocity after a maximal 25-m bout. Path-flow analysis was performed with the estimation of linear regression standardized coefficients between exogenous and endogenous variables. To verify the model fit, root mean square residual was computed. The active drag presented significant association with all exogenous variables, except for stroke length and stroke frequency. Confirmatory model excluded the frontal surface area (RMSR>0.1). Even so, 95% of active drag was explained by remaining variables in the model. Confirmatory path-flow model can be considered as not suitable of the theory. In order to increase the model fit, in a near future it is advice to develop new frontal surface area estimation equations specific for young swimmers rather than using models developed with adult/elite swimmers. **Key words:** AGED-GROUPS, BIOMECHANICS, ANTHROPOMETRICS, HYDRODYNAMICS.

✉ **Corresponding author.** Department of Sport Sciences, Polytechnic Institute of Bragança. Campus Sta. Apolónia, Apartado 1101, 5301-856 Bragança, Portugal.
E-mail: barbosa@ipb.pt
Submitted for publication June 2010.
Accepted for publication September 2010.
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.4100/jhse.2010.53.08

INTRODUCTION

Swimmer's goal is to achieve the highest velocity to travel the event distance fastest. Swimming velocity is dependent from two external forces: (i) propulsion and; (ii) drag. To displace, the swimmer has to be able at least to produce propulsion with an intensity equal to the drag resisting forward motion. By this way, the swimmer is able to maintain a uniform movement:

$$v = v_0 = \text{constant} \quad (1)$$

Where v is swimming velocity at a given time instant and v_0 the swimming velocity at the beginning. However, there are velocity variations between each stroke cycle, but mainly within it:

$$v = v_0 + \Delta v(t) \quad (2)$$

Where v is swimming velocity at a given time instant, v_0 the swimming velocity at the beginning and t the time instant. Changes in swimming velocity considering a given period of time defines the swimming acceleration and it is dependent upon the applied resultant force and the inertial term, as stated by the Newton's second equation:

$$F = m \cdot a \quad (3)$$

Where F is force, m is mass and a is acceleration. Relating the acceleration to both external forces submitted to a swimmer (i.e., propulsion and drag) and his inertial characteristics (i.e., body mass and added water mass):

$$P + D = (BM + AM) \cdot a \quad (4)$$

Where P is propulsion, D drag force, BM body mass, AM added water mass and a acceleration. So, the assessment of the drag force is one of the most challenging topics for swimming researchers and practitioners as it has a direct effect on the swimming performance.

The competitive swimming literature already reported several variables that are related to the drag force. Some of those variables are related to anthropometric (Huijing et al., 1988), biomechanical (Marinho et al., 2010) and hydrodynamic (Tousssaint et al., 2004) variables. Added to this, there are some evidence of relationships between some anthropometrical and biomechanical variables (Grimston & Hay, 1986), anthropometrical and hydrodynamic variables (Arellano et al., 2003), as well as, biomechanical and hydrodynamic variables (Kjendlie et al., 2008).

The above cited researches are mainly exploratory ones, identifying variables related to active drag. Regarding to this, little is known on how all these variables related ones with each others to determine the drag force. The best approach to do so is to adopt confirmatory research designs. The development of structural equation modeling (e.g., path analysis) seems to be one of the best options with such aim.

Indeed, the development of "flow chart" models confirming the relationships between drag force and other determinant variables was never attempted in competitive swimming for young or adult/elite athletes. One single study performed such kind of data analysis but, relating biomechanical and energetics variables with performance in young swimmers (Barbosa et al., 2010b).

Therefore, the aim of this paper was to develop a structural equation modeling (i.e., path analysis) for active drag force (Da) based on selected anthropometric, hydrodynamic and biomechanical variables in young competitive swimmers. The theoretical model was developed according to main review papers about these relationships (Lavoie & Montpetit, 1986; Barbosa et al., 2010a). The theoretical model designed is presented in Figure 1.

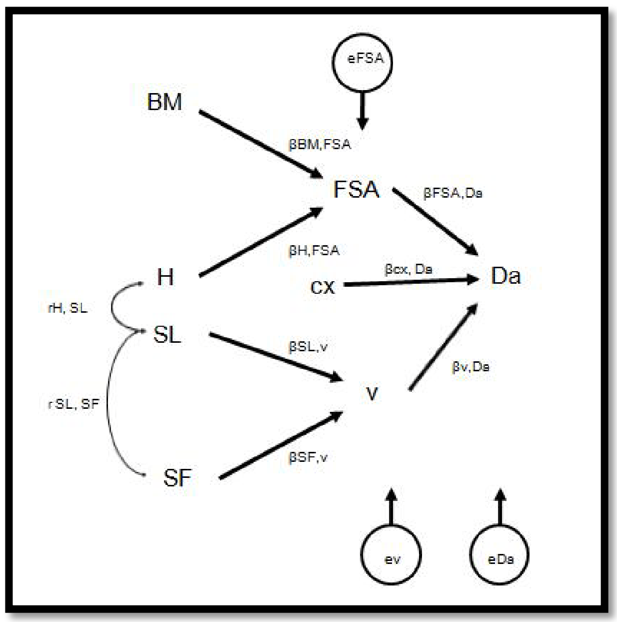

***Figure 1**. Theoretical path-flow model. H= height; BM= body mass; FSA= frontal surface area; SL= stroke length; SF= stroke frequency; v= swimming velocity; cx= drag coefficient; Da= active drag; $x_i \rightarrow y_i$= variable y_i depends from variable(s) x_i; $x_i \leftrightarrow y_i$ variable x_i is associated to variable y_i.*

MATERIAL AND METHODS

Subjects

Sixteen male swimmers (12.50±0.51 years-old; Tanner stages 1-2) with several competitive levels were evaluated. Parents and coaches gave their consent for the swimmers participation in this study. All procedures were in accordance to the Declaration of Helsinki in respect to Human research. The Institutional Review Board of the Polytechnic Institute of Bragança approved the study design.

Anthropometrics data collection

For anthropometrical assessment it was recorded the body mass (SECA, 884, Hamburg, Germany), height (SECA, 242, Hamburg, Germany) and estimated the frontal surface area as (Clarys, 1979):

$$FSA = \frac{6.93BM + 3.50H - 377.2}{10000} \quad (5)$$

Where *BM* is the body mass in [kg] and *H* is the height in [cm].

Hydrodynamics data collection

The hydrodynamic variables assessed were the drag coefficient (cx) and the *Da* with the velocity perturbation method (Kolmogorov & Duplisheva, 1992):

$$D = \frac{D_b v_b v^2}{v^3 - v_b^3} \quad (6)$$

Where *D* in [N] is the swimmer's active drag at maximal velocity, D_b in [N] is the resistance of the perturbation buoy and v_b and *v* are the swimming velocities in [m·s^{-1}] with and without the perturbation device in two maximal 25 m freestyle bouts, respectively. Time spend to cover between the 11th and the 24th meter was measured by an expert evaluator with a chronometer (Golfinho Sports MC 815, Aveiro, Portugal). Drag coefficient (C_x) was calculated based on the Newtonian drag equation:

$$C_x = \frac{2D}{\rho FSA v^2} \quad (7)$$

Where C_x is the drag coefficient, *D* is the drag force in [N], *ρ* is the density of the water in [kg·m^3], *v* is the swimming velocity in [m·s^{-1}] and *FSA* is the projected frontal surface area of the swimmers in [cm^2].

Biomechanics data collection

For biomechanical assessment swimming velocity, stroke frequency and stroke length were measured. Each swimmer made a maximal 25-m swim with an underwater start. Subjects performed the bout alone with no other swimmer in the same swim lane to reduce the drafting or pacing effects. The swimmers were advised to reduce gliding during the start. Swimming velocity was measured in the middle 15-m as:

$$\bar{v} = \frac{d}{t} \quad (8)$$

Where v is the mean swimming velocity in [m·s^{-1}], d the distance covered by the swimmer in [m], *t* the time spent to cover such distance in [s] measured with a chronometer by an expert evaluator. The stroke frequency (SF) was measured with a crono-frequency meter from 3 consecutive stroke cycles, in the middle of the 15-m distance by an expert evaluator as well. Stroke length was estimated as (Craig & Pendergast, 1979):

$$SL = \frac{\bar{v}}{SF} \quad (9)$$

Where *SL* is the stroke length in [m], *v* is the swimming velocity in [m·s-1] and *SF* is the stroke frequency in [Hz].

Statistical procedures

The normality and homocedasticity assumptions were checked respectively with the Shapiro-Wilk and the Levene tests. Descriptive statistics (minimum, maximum, mean and one standard deviation) from all variables were calculated. It was computed the Spearmen´s Rank Correlation Coefficient between *Da* and all remains variables. The statistical significance was set at $p \leq 0.05$.

Path analysis is one special case of structural equation modeling analysis. Structural equation modeling is a mathematical approach for testing and estimating causal relationships using a combination of statistical data and qualitative causal assumptions previously defined by the researcher that will be (or would not be) confirmed (Barbosa et al. 2010b). This procedure, rather than identifying variables suggests the kind of relationship exists (e.g., direct, indirect and spurious effects). Therefore, this kind of data analysis aims confirming the existence of relationships between exogenous and endogenous variables.

Path-flow analysis was performed with the estimation of linear regression standardized coefficients between the exogenous and endogenous variables. All assumptions to perform the path-flow analysis were taken into account. When appropriate, according to the theoretical model, simple or multiple linear regression models were computed. Standardized regression coefficients (β) were considered. Significance of each β was assessed with the t-Student test ($p<0.05$). The effect size of the disturbance term, reflecting unmeasured variables, for a given endogenous variable, was $1-R^2$.

To verify the fit of the model, root mean square residuals (RMSR) was computed:

$$RMSR = \sqrt{\frac{\sum_{i=1}^{p}\sum_{i=1}^{q}(rij - pij)^2}{p+q}} \quad (10)$$

Where r is the Pearson correlation coefficients and p the correlation predicted by the model (based on total effect, i.e., the addiction of the direct and indirect effects plus spurious effects). Qualitatively, it is considered that if: (i) RMSR < 0.1 the model adjust to the theory; (ii) RMSR < 0.05 the model adjusts very well to the theory and; (iii) RMSR ~ 0 the model is perfect.

RESULTS AND DISCUSSION

Table 1 presents descriptive statistics from all variables studied. Descriptive statistics reveals that the sample was composed of a somewhat heterogeneous group of swimmers, as the dispersion data assessed by both the standard deviation and the range of values were moderate-high. As an example, *Da* was considered in this research as endogenous variable, ranged between 18.47 N and 60.18 N.

Table 1. *Descriptive statistics of anthropometrics, biomechanics and hydrodynamics variables.*

	Mean	Standard deviation	Minimum	Maximum
BM [kg]	43.48	7.81	32.30	61.50
H [cm]	151.9	9.81	136.0	164.0
FSA [m^2]	0.045	0.008	0.035	0.062
SL [m]	1.53	0.17	1.25	1.85
SF [Hz]	0.93	0.06	0.85	1.03
v [$m \cdot s^{-1}$]	1.40	0.12	1.16	1.55
Cx [*adimensional*]	0.31	0.09	0.22	0.51
Da [N]	38.10	13.14	18.47	60.18

Table 2 presents the correlation between *Da* and remaining variables analyzed. The *Da* presented significant association with all exogenous variables, except for *SL* and *SF*. The highest correlation coefficients were verified between *Da* and *Cx* (r = 0.74; p<0.001) and *H* (r = 0.72; p<0.001).

Table 2. Correlation matrix between swimming performance and remains variables.

	r_s	p value
H [m]	0.72	<0.001
BM [kg]	0.68	<0.001
FSA [m^2]	0.71	<0.01
SL [m]	-0.30	NS
SF [Hz]	0.35	NS
v [$m \cdot s^{-1}$]	0.44	0.05
Cx [*adimensional*]	0.74	<0.001

Figure 2 presents the confirmatory path-flows for *Da*. Only one path, between *FSA* and *Da,* was non-significant (β = 0.04; p>0.05). The confirmatory model explained 95% of *Da* for both path-flows including (Figure 2A) and deleting (Figure 2B) the *FSA* path linking it to *Da*. The *SRMR*, quantifying the fit of the model purposed, was higher than 0.10. So, the confirmatory path-flow model cannot be considered as suitable of the theory presented.

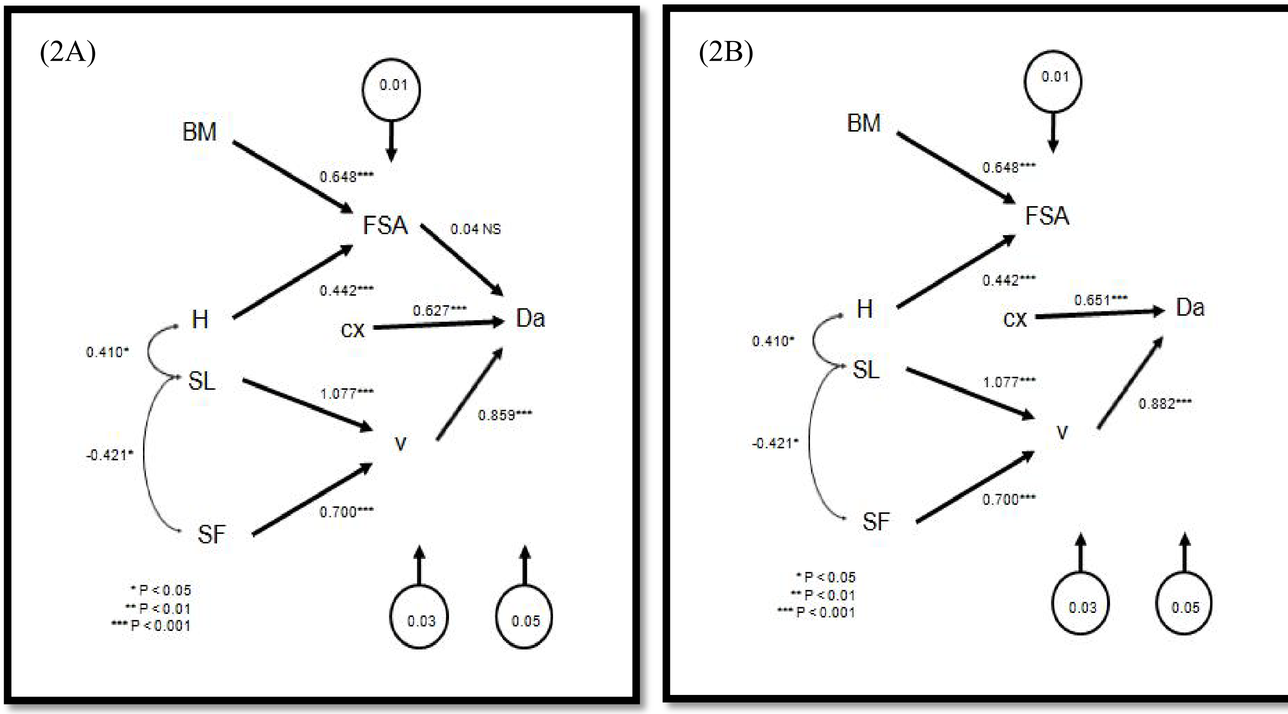

Figure 2. *Confirmatory path-flow models including non-significant paths (2A) and deleting non-significant paths with subsequent re-computation of remain data (2B). H= height; BM= body mass; FSA= frontal surface area; SL= stroke length; SF= stroke frequency; v= swimming velocity; cx= drag coefficient; Da= active drag.*

The aim of this research was to develop a path-flow analysis model for young swimmers' active drag based on selected anthropometrics, biomechanics and hydrodynamics variables. The main result was that the confirmatory model explained 95% of the *Da* after the elimination of the *FSA* path which was non-significant (SRMR >0.10).

Mean data are somewhat within the range of values reported in the literature for swimmers with similar gender, chronological and biological ages (Silva et al., 2007; Schmidt & Ungerechts, 2008; Marinho et al. 2010). Descriptive statistics reveals that the sample was composed of a somewhat heterogeneous group of swimmers, as the dispersion data assessed by both the standard deviation and the range of values were moderate-high. Moderate-high data dispersion allowed analyzing hypothetical relationships between *Da* and selected anthropometrics, hydrodynamics and biomechanics variables.

The *Da* presented significant association with all exogenous variables, except for *SL* and *SF*. The *Da* is computed by the Newtonian equation:

$$D_a = \frac{1}{2} \rho \cdot v^2 \cdot FSA \cdot C_x \qquad (11)$$

Where *Da* is the active drag, ρ is the water density, v is the swimming velocity, *FSA* the frontal surface area and *Cx* the drag coefficient. So, it can be resumed to its main determinant which is the swimming velocity as:

$$D_a = K \,.\, v^2 \quad (12)$$

Where *Da* is active drag, *K* is a constant factor including water density, frontal surface area and drag coefficient, since presumably it does not significantly change during the stroke cycle. Plus, on regular basis (Barbosa et al., 2008) it is described that in close and cyclic movements:

$$v = SL \cdot SF \quad (13)$$

Where *v* is the swimming velocity, *SL* the stroke length and *SF* the stroke frequency. Combining equations 12 and 13 becomes:

$$D_a = K \cdot (SL \cdot SF)^2 \quad (14)$$

So, it was hypothesized that *SL* and *SF* would affect significantly the *Da*. However the hypothesis was not accepted. The explanation might be that other variables besides the stroke cycle variables, included in the K factor, have a major impact. For instance, the *K* factor has, as indirect mediators, several hydrodynamic parameters (e.g., Reynolds number, Strouhal number) that are greatly affected by anthropometrical variables (Arellano et al., 2003).

The highest correlation coefficients were verified between *Da* and *Cx*, as well as, between *Da* and *H*. Regarding the *Da* versus *Cx* relationship, some careful has to be taken. *Da* and *Cx* where obtained with the same testing protocol (Kolmogorov & Duplisheva, 1992) based on equations 6 and 7, respectively. So, it might the case of a multicolinearity effect. As reported in the previous paragraph, *Da* is related to some hydrodynamic variables, as for example, the Reynolds number or the Strouhal number. Added to this, those hydrodynamic variables are dependent from the bodies' morphology and geometry. So, *H* being a morphological variablel, presented one of the highest correlation coefficients as it is indirectly included in the *K* factor member that determines the *Da*.

Ninety five percent of active drag was explained by remaining variables in the model. It means that anthropometrics, hydrodynamics and biomechanics are the main determinant domains for *Da*. However, the confirmatory model excluded the frontal surface area, although remain paths were significant. As consequence, the confirmatory path-flow model was not considered as suitable of the theory. When assessing *FSA* there are two options: (i) perform a direct evaluation, measuring the area with an imagiographic or a photometric technique; (ii) estimate the *FSA* based on equations previously developed and validated. The equation adopted was developed with elite swimmers from the seventies by Clarys (1979). The present paper is about young swimmers and not adult/elite swimmers. So, Clary's equation might present some bias when applied to age-group swimmers. Added to this, swimmers from the XXI century presents different characteristics from the ones of the seventies (Barbosa et al., 2006), including possibly the anthropometrical ones. So, to increase the model good-of-fit in nearby structural equation modeling's the solution might be to perform a direct measurement of the *FSA* or to develop new brand estimation equations specifically for young competitive swimmers.

It can be considered as main limitations of the study: (i) the model is only suitable to be used with young swimmers and it is not appropriate to be extrapolated for adult/elite swimmers; (ii) the model is only suitable for boys and not for girls; (iii) since 5% of the *Da* prediction is not included in the model, probably there are some remaining variables that might be included in the model to increase its accuracy and; (iv) the need to improve the fit of the model including in it *FSA* data from direct body evaluations or estimations based on new equations specifically developed for young swimmers.

CONCLUSIONS

Confirmatory path-flow model can be considered as not suitable of the theory. Main limitation of the model is related to the *FSA* estimation equation that does not fit in the model. Nevertheless, *Da* was highly predictable based on selected anthropometrical, biomechanical and hydrodynamic variables. For a near future it is advice to develop new *FSA* estimation equations specific for young swimmers rather than using the ones developed with adult/elite swimmers.

REFERENCES

1. ARELLANO R, PARDILLO S, GAVILAN A. Usefulness of the Strouhal number in evaluating human under-water undulatory swimming. In: JC Chatard (ed.). *Biomechanics and Medicine in Swimming IX*. University of Saint-Etienne: Saint-Etienne; 2003, pp. 33-38. [Full text] [Back to text]
2. BARBOSA TM, BRAGADA JA, REIS VM, MARINHO DA, CARVALHO C, SILVA AJ. Energetics and biomechanics as determining factors of swimming performance: updating the state of the art. *J Sci Med Sports*. 2010a; 13: 262-269. doi:10.1016/j.jsams.2009.01.003 [Back to text]
3. BARBOSA TM, COSTA MJ, MARINHO DA, COELHO J, MOREIRA M, SILVA AJ. Modeling the links between age-group swimming performance, energetic and biomechanic profiles. *Ped Exerc Sci*. 2010b; 22:379-391 [Back to text]
4. BARBOSA TM, FERNANES RJ, KESKINEN KL, COLAÇO P, CARDOSO C, SILVA J, VILAS-BOAS JP. Evaluation of the energy expenditure in competitive swimming strokes. *Int J Sports Med*. 2006; 27: 894-899. [Abstract] [Back to text]
5. CLARYS JP. Human morphology and hydrodynamics. In: Terauds J and Bedingfield EW (Eds). *Swimming III*. University Park Press: Baltimore; 1979, pp. 3-41. [Back to text]
6. CRAIG A, PENDERGAST D. Relationships of stroke rate, distance per stroke and velocity in competitive swimming. *Med Sci Sports Exerc*. 1979; 11:278-283. [Full text] [Back to text]
7. GRIMSTON SK, HAY J. Relationship among anthropometric and stroking characteristics of college swimmers. *Med Sci Sports Exerc.* 1986; 18:60-68. [Abstract] [Back to text]
8. HUIJING P, TOUSSAINT HB, MACKAY R, VERVOON K, CLARYS J, HOLLANDER AP. Active drag related to body dimensions. In: B Ungerechts, K Wilke, K Reischle (Eds). *Swimming Science V*. Human Kinetics Books: Champaign, Illinois; 1988, pp. 31-37. [Back to text]
9. KJENDLIE PL, STALLMAN RK. Drag characteristics of competitive swimming children and adults. *J Appl Biomech*. 2008; 24:35-42. [Abstract] [Back to text]
10. KOLMOGOROV SV, DUPLISHEVA A. Active drag, useful mechanical power output and hydrodynamic force coefficient in different swimming strokes at maximal velocity. *J Biomech*. 1992; 25:311-318. doi:10.1016/0021-9290(92)90028-Y [Back to text]
11. LAVOIE JM, MONTPETIT R. Applied Physiology of swimming. *Sports Med*. 1986; 3:165-188. [Abstract] [Back to text]

12. MARINHO DA, BARBOSA TM, COSTA MJ, FIGUEIREDO C, REIS VM, SILVA AJ, MARQUES MC. Can 8-weeks of training affect active drag in young swimmers? *J Sports Sci Med*. 2010; 9:71-78. [Full text] [Back to text]
13. SCHIDT A & UNGERECHTS BE. The effect of cognitive intervention on stroke distance in age-group swimmers. In: T Nomura, BE Ungerechts (Eds.). *The Book of Proceedings of the 1st International Scientific Conference of Aquatic Space Activities*. University of Tskuba: Tsubuka; 2008, pp. 380-387. [Back to text]
14. SILVA AJ, COSTA AM, OLIVEIRA PM, REIS VM, SAAVEDRA J, PERL J, ROUBOA A, MARINHO DA. The use of neural network technology to model swimming performance. *J Sports Sci Med*. 2007; 6:117-125. [Full text] [Back to text]
15. TOUSSSAINT H, ROOS P, KOLMOGOROV S. The determination of drag in front crawl swimming. *J Biomech*. 2004; 37:1655-1663. doi:10.1016/j.jbiomech.2004.02.020 [Back to text]

1

